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Test of an Otto gas engine with producer gas

Mechanical Engineering

B. S.

1910

TEST OF AN OTTO GAS ENGINE WITH PRODUCER GAS

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THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE

IN MECHANICAL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

OF THE

UNIVERSITY OF ILLINOIS

JUNE, 1910

UNIVERSITY OF ILLINOIS

May 31 1910

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED Test of an Otto Gas Engine with Producer Gas.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

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Introduction.

In the year 1862, it was pointed out by a French engineer, Beau de Rochas, that in order to get a high economy in a gas engine, certain conditions of operations were necessary. The most important of these conditions, is that the explosive mixture should be compressed to a high pressure before ignition. In order to accomplish this, he proposed that the cycle of operation should occupy four strokes or two complete revolutions of the engine, and that the operations should be as follows:

(1) Suction or admission of charge of air and gas throughout complete forward stroke.

(2) Compression of the explosive mixture during the whole of the return stroke, so that it finally occupies only the clearance space.

(3) Ignition of the charge at the end of the second stroke, and expansion throughout the whole of the next forward stroke.

(4) Exhaust beginning at the end of the forward stroke, and continuing throughout the whole of the last return stroke.

This cycle was not actually used until 1876, when Dr. Otto adopted it in his engine, and thereby produced the modern gas engine. The four cycle of Beau de Rochas is now universally known as the Otto cycle.

As in practically all Otto cycle engines, the engine is single acting and has a long trunk piston which acts as a cross-head, and also permits the use of several piston rings which prevent the leakage of gas past the piston. The engine is made single acting because the cylinder would get too hot for continuous running if it were double acting: and moreover a piston rod and

stuffing box give great trouble if exposed to the high temperature of the burning gasses.

Referring to Fig. I, A is the shaft which carries the valve cams, and is driven by gear from the main shaft. The exhaust cam works against a roller carried on the free end of the lever G. The exhaust valve E has a long stem projecting downward, and resting on the upper side of the lever G. The spring surrounding the stem serves to bring the exhaust valve back to its seat, and to keep the stem in contact with the guide lever.

The inlet cam works against the roller carried on the free end of the bell crank H. The construction of the inlet valve is similar to that of the exhaust valve. The gas valve is operated in the same way with another cam bell crank. One end of this valve vrank presses against the valve stem, and the other has a roller which slides on its shaft. This roller is connected by means of a bell crank to the governor. When the speed runs down below 220 r. p. m. the governor moves this bell crank which in turn pushes the roller, on the free end of the gas inlet bell crank, over on its shaft. This causes it to work against the gas cam, on the cam shaft, thus opening the gas valve. Incidentally the vertical shaft I carries the governor. The igniter is also operated by means of an eccentric on the cam shaft, which at the proper instant operates the plunger J working on the guide D, thus making and breaking the electric current through the wire S at the terminals of the igniter F.

The cylinder head and the cylinder are thoroughly water jacketed as, owing to the extreme heat to which these parts are

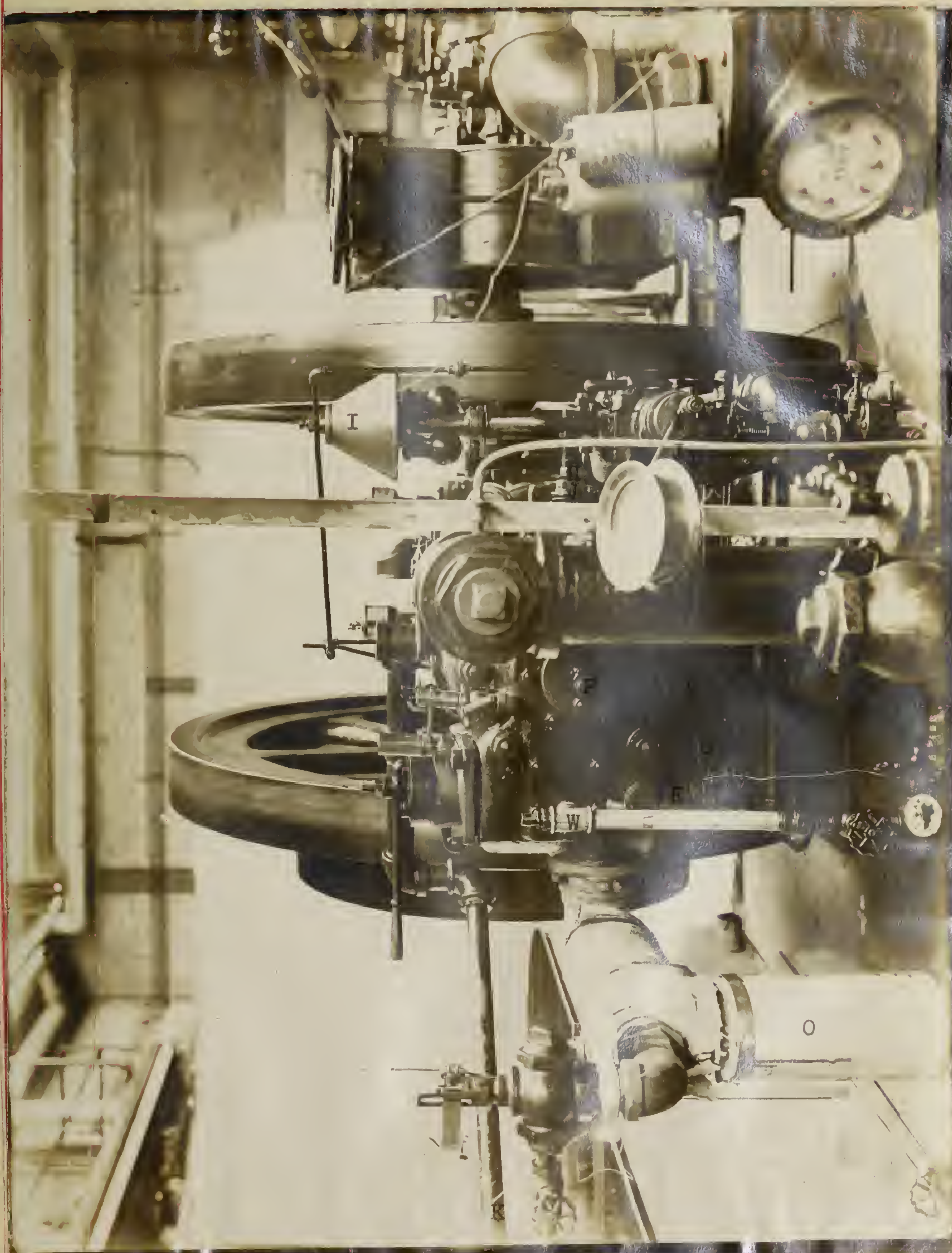

Fig. 1.
End View of Otto Gas Engine.

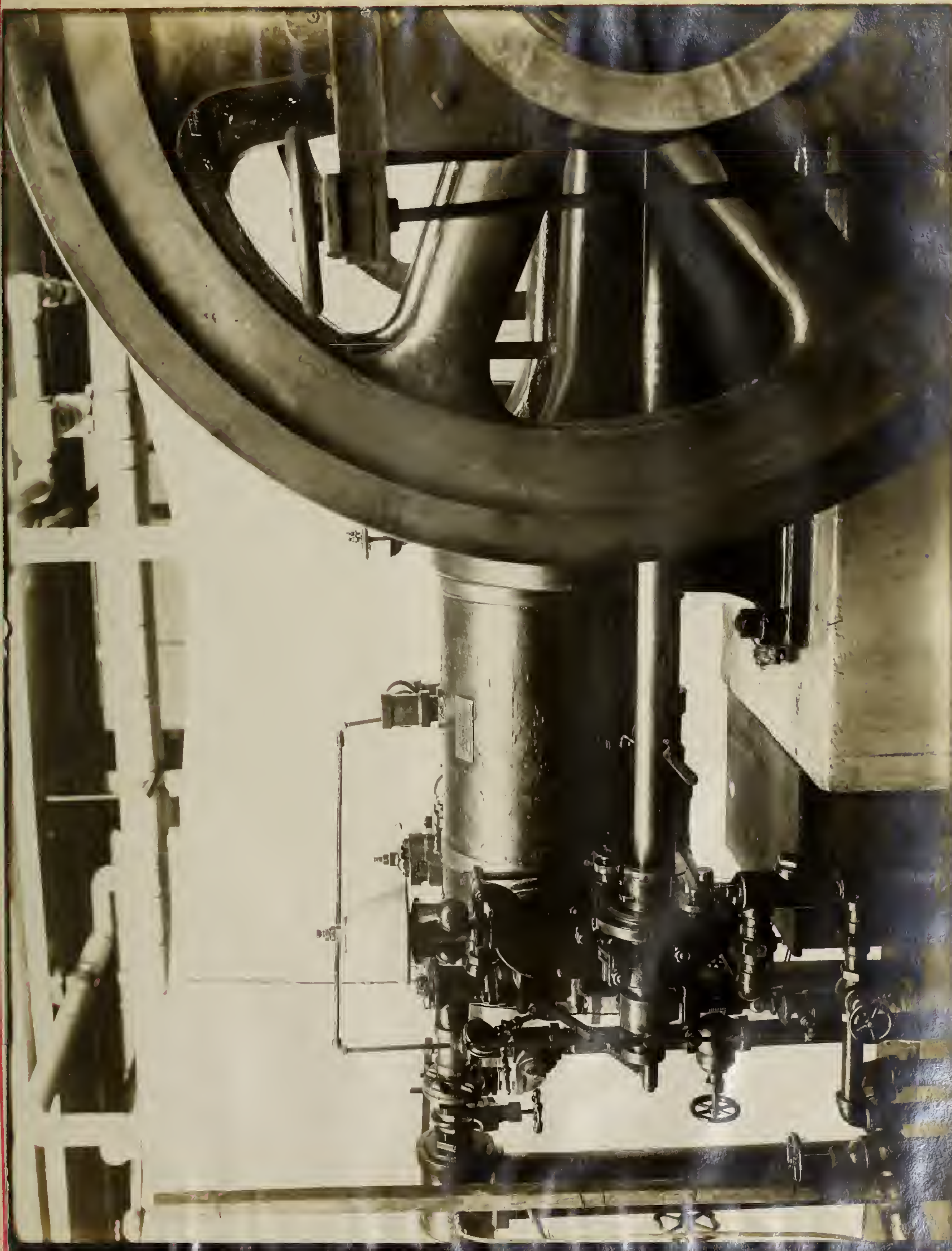

Fig. 2.
Side View of Otto Gas Engine.

subjected, they would soon become red hot if no means were provided for keeping the temperature down. The cooling water enters at W and discharges at K.

The gas and air enter the mixing chamber by separate inlets, in proportionate amounts, which can be regulated, and the mixture is conducted through a port, leading to the cylinder head, in which the inlet valve is located. The exhaust gas~~s~~es escape through O.

The operation of this engine is essentially as outlined above. The admission of the charge of gas and air takes place during the first outward stroke of the engine. The exhaust valve E is closed and the inlet valve J is open, and closes only when the piston is at the end of the stroke, and the cylinder is full of the explosive mixture. During the return stroke both valves are closed as the charge is compresses until at the end of the stroke it occupies the clearance space. Shortly before the end of this stroke the igniter eccentric has brought the igniter terminals together, completing an electric circuit. When the crank is nearly on its dead center, the igniter terminals are separated by means of a coil spring, and as they fly apart the circuit is broken, and a spark passes between the terminals, igniting the charge. An immediate rise of pressure occurs and the piston is forced outward, both valves remaining closed until just before the end of the explosion stroke, when the exhaust valve E opens. During the whole of the last return stroke, the exhaust valve E remains open, and the products of combustion are forced through O to the atmosphere. The exhaust valve closes as the piston completes its stroke, and every-

thing is in readiness to recommence the cycle.

Thermodynamics of the Otto Cycle.

In internal combustion motors, the explosive mixture consists of air mixed with a comparatively small volume of the gases or liquid fuel. For instance, if the engine uses gas from the city mains, the mixture will average about eight or nine parts of air to one of the gas. This mixture can be regarded, up to the time of the explosion, as if it were pure air. Also the products of combustion, after the explosion is completed, have physical properties but very slightly different from those of air, and consequently, the working substance in the cylinder can be regarded as pure air, without serious error. In the following discussion of what occurs in the cylinder of the gas engine, it is assumed throughout that the substance in the cylinder is pure air.

The processes taking place in the engine cylinder are best represented by means of two diagrams, the pressure-volume diagram and the temperature-entropy diagram. Entropy is defined as that quanity which varies directly as the heat in a substance.

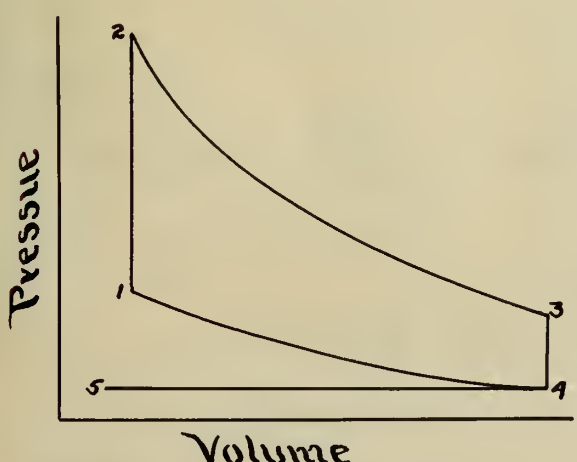

Fig. 3.

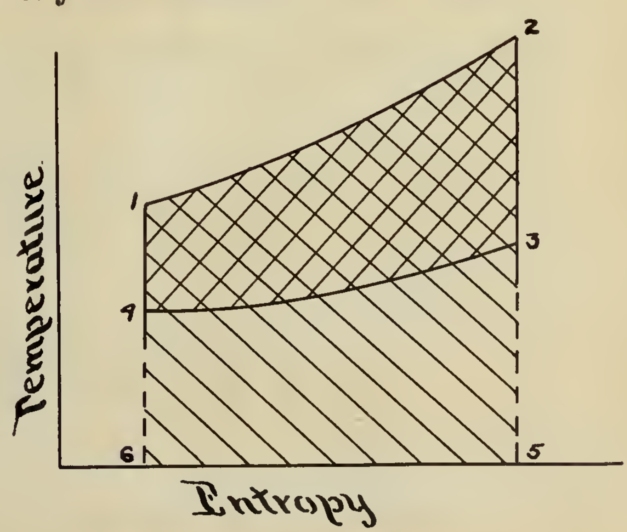

Fig. 4.

The above diagrams show the processes which take place in the gas engine cylinder, under ideal conditions during a complete cycle.

Referring to Fig. 3, the mixture is admitted along the line 4,5 and is compressed along the line 4,1. At 1 the charge is ignited, and the pressure arises along the line 1,2. The burnt gases then expand along the line 2,3. At 3 the pressure drops to atmospheric and the gases are exhausted at this pressure. The same processes are represented in Fig.4 . When the charge is ignited, the temperature rises and heat passes into the medium, as shown by the area under the line 1,2. At 2 the gas expands adiabatically as shown by the line 2,3. At 3 the pressure drops to atmospheric and hence the temperature drops, while heat passes out of the gas. This is shown by the area under the line 3,4. From 4 to 1 the gas is compressed, adiabatically and the same process is repeated as before.

The actual conditions are not precisely as indicated above, but they are sufficiently close for the purpose of this discussion.

Referring to Fig. 4, the efficiency of the cycle is evidently,

$$\frac{\text{area } 1,\ 2,\ 3,\ 4,}{\text{area } 1,\ 2,\ 5,\ 6,} = \frac{C_v\ (-T_1 + T_2\ ) - C_v\ (\ T_3 - T_4\ )}{C_v\ (\ T_1 - T_2\ )}$$

Hence the efficiency is,

$$\frac{(-T_1 + T_2 - T_3 + T_4\ )}{(-T_1 + T_2\ )} = 1- \frac{(\ T_3 - T_4\ )}{(-T_1 + T_2\ )}$$

From the above discussion, it is evident that an increase in the compression with a corresponding increase in T_1 will

cause an increase in the efficiency of the operation.

Object of the Tests as Originally Intended.

The object of the tests, as originally intended, was to determine the efficiency and the heat balance of the engine, operating on producer gas containing zero percent of hydrogen, and running under loads of 10, 15, and 20 H. P. For each different load it was intended to run at three different compressions - 120, 150, and 200 lbs. per sq. in. - making nine separate tests in the series. The same tests were then to be repeated, using producer gas containing about 16% hydrogen. These tests were to be run for the purpose of determining the effect of increasing the compression on the efficiency, and to determine the relative efficiencies of the engine when running at the different loads on the two kinds of gas.

Causes that Prevented Carrying out the Tests as Originally Planned.

In order to obtain the different compressions, an attempt was made to put in liners behind the crank pin bearing. These liners were to be of the proper thickness to produce the desired compressions. The existing compression was first obtained by means of an indicator having a light spring. The engine was run at full speed for about one-half hour, and then the gas supply was quickly shut off, and an indicator card taken as soon as possible. In this way the compression was obtained more accurately than would have been possible had a spring, sufficiently heavy to withstand the explosive pressure, been used. Then, by the use of the equation, $\frac{p\,v}{T} = \frac{p1v1}{T1}$ the volumes necessary for the desired compressions were

computed, and knowing the dimensions of the cylinder, the widths of the liners were computed.

When it was attempted to run the engine with one of these liners in, it was found that the fly wheels could not be turned over. Investigation revealed the fact that this was due to a diminution in the diameter of the piston at the inside end, and a corresponding decrease in the cylinder diameter. It was then decided that this difficulty could be eliminated by the use of a compression plate. A compression plate about 3/4 in. in thickness was accordingly made, and fastened to the piston with screws having counter-sunk heads. With this compression plate in place, the engine failed to develop its rated horse-power. The valves were then carefully reset. This necessitated the designing of new cams which were carefully located on the cam shaft. A compression head having a smoother surface was made, and put on, and with the new cams in place, and all bearings carefully scraped and adjusted, another attempt was made to run the engine on producer gas. This test disclosed an object of such a serious nature, that the test, as originally intended, was abandoned. After the engine was run for some time preignition began and the power rapidly dropped off. The preignition was not due to the high compression, as producer gas will easily stand pressure much higher than was used in this case, but was due to the compression head becoming red hot, and being of hollow cast iron, the heat could not be radiated fast enough. The compression plate was then taken off, and another attempt was made to run on producer gas. The engine would not carry more than one-half rated load, and as before stated, the original test was abandoned.

The cause of this failure was doubtless due to the low compression, which resulted in incomplete combustion.

Object of Tests as Finally Run.

The object of test as finally run was (1) to determine wherein the losses in mechanical efficiency, which were found to be excessive, occurred, by running the engine with an electric motor, (2) to determine if the failure of the engine to carry full load on producer gas was due to the low compression, which resulted in incomplete combustion, and (3) to determine the efficiency, to make heat balances, and to obtain all other data possible for the engine running under the following conditions: (1) operating on producer gas, at a load of 10 H. P., and a compression of 105 lbs. per sq. in. (2) operating on illuminating gas, at loads of 10, 15 and 20 H. P., and at a compression of 105 lbs. per sq. in.

In order to determine whether or not the combustion in the cylinder was complete, continuous samples of the entering and exhaust gases were taken and analyzed.

Subject.

Friction Test of Otto Gas Engine.

Object.

The object of this test, as stated above, was to determine wherein the losses in mechanical efficiency, which were found to be excessive, occurred, by running the engine with an electric motor.

Apparatus.

Otto Gas Engine No. 8965,23 H. P., R. P. M. 220

Induction motor No. 319807, 7.5 H. P., 2 phase, volts 400, amps.10.7 full load speed 1120, alternations 7200.

Westinghouse portable wattmeter A. C. No. 34434, volts 200 to 400, amps. 5 to 10, alternations 7200.

Description of Apparatus.

The description of the Otto Gas Engine is given on pages 1 and 2 of this thesis.

The distinguishing feature of the induction motor is the rotating magnetic field. It is thus explained: In Fig. 5 let ab, cd be two pairs of poles of a motor, a and b being wound from one pair of wires of a two phase alternating current, and c and b being wound from the other pair of wires, the two phases being 90 degrees apart. At the instant when a and b are receiving maximum current, so as to make (a) a north pole and (b) a south pole, c and d are demagnetized, and a needle placed between the poles would stand as shown in the cut. During the progress of the cycle of the current, the magnetic flux at (a) decreases, and that at (c) increases, causing the point of resulting maximum intensity to shift, and the needle to move clock wise toward (c). A complete revolution of the resultant point is performed during each cycle of the current. An armature, placed within the ring, is made to rotate simply by the shifting of the magnetic field without the use of a collector ring.

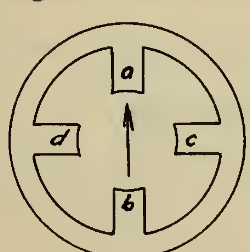

Fig. 5.

The wattmeter is a special form of electro dynamometer the connections of which are shown in Fig.6. A fixed coil of coarse wire B is connected in series with the receiving circuit,

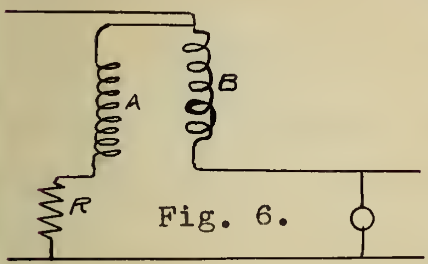

Fig. 6.

to which the power to be measured is delivered, and a suspended or pivoted coil of fine wire A is connected across the supply mains, in series with a noninductive resistance R. The total current which is deliver-ed to the receiving circuit flows through the fixed coil B. A current, proportional to the supply voltage, flows through the pivoted coil A, and the force action between the coils causes coil A to move, and carry a pointed over a divided scale.

Description of Test.

The motor was belted to the fly-wheel pulley, and the wattmeter wired in the motor circuit. The oscillating parts of the engine were run as follows: (1) The cam shaft was disconnected, and the fly-wheels, piston and connected parts were run with the motor. (2) The connecting rod and piston were removed, and the fly-wheels were run alone. (3) The cam shaft was connected to the main shaft, and the main shaft and the cam shaft were run together, the governor and valves being disconnected. (4) The valves and governor were connected to the cam shaft, and the fly-wheels, cam shaft, valves and governor were run with the motor. (5) The engine, completely assembled, was run with the electric motor.

The reading of the wattmeter, the R. P. M. of the motor, and the R. P. M. of the main shaft were taken in each of the above cases.

A brake test was then run on the electric motor, and, by means of the data thus obtained, a curve was plotted showing relation between actual wattmeter reading and brake horse-power. The diameters of the motor and engine pulleys were carefully measured. Knowing these diameters, the revolutions of the fly-wheels, provided no slippage occurred, could be computed. Knowing the mean wattmeter reading in each of the tests above described, the necessary horse-power was obtained by means of this curve.

Sample Calculations.

Diameter of engine pulley,------------------------------- 48 in.

Diameter of motor pulley,-------------------------------- 9 in.

R. P. M. of motor,-------------------------------------- 1223

R. P. M. of engine,(no allowance being made for slippage)

$$1223 \times \frac{9}{48} = 227.5.$$

Conclusions.

By referring to the data sheet on page 12a,it is seen that the largest loss in mechanical efficiency, occurs in the piston, which required 1.52 H. P. The next largest loss is in the fly-wheels and main shaft, which required 1.34 H. P. These losses would undoubtedly be higher when a load is on the engine. This is due to the increased pressure between the bearing surfaces.

Friction Test

Data.

Part.	Loss H.P.	Loss %
Fly Wheels.	1.34	42.1
Piston and Connecting Rod.	1.52	47.8
Cam Shaft.	0.12	3.7
Valves and Governor.	0.20	6.4
Engine Complete.	3.18	100.0

Efficiency Test of Otto Gas Engine on Producer Gas.

Object.

The object of this test was to obtain data for determining the mechanical and thermal efficiencies, and the heat balance of the engine running on producer gas, under a constant load of 10 H.P.

Apparatus.

The following apparatus was used: The Otto Suction Gas Producer, capacity 60 H. P., made by Otto Gas Engine Works, Phil., Pa.
Otto gas engine No. 8965, speed 220 R. P. M., 23 H. P., cylinder 10 x 19 in., 4 cycle.

One thermometer ----- range 0 - 1000° Fahr.

One thermometer ----- range 0 - 200° Fahr.

Two thermometers ---- range 0 - 100° Fahr.

Crosby indicator No. 6183, spring No. 50, scale 400, 1/8 in. piston.

Gas meter No. 122300, range 0 - 100,000,000 cu. ft.

Prony brake.

Two Buffalo scales.

Speed counter.

Water tank ----- No. 287.

Description of Apparatus.

The Otto Gas Engine, made by the Otto Gas Engine Works, Philadelphia, Pa., is described on page 1 of this thesis. The producer used is a suction producer made by the Otto Gas Engine Works, Philadelphia, Pa. A diagrammatic view of the producer is shown in Fig.7, page 13a.

A distinctive feature of the suction producer is that

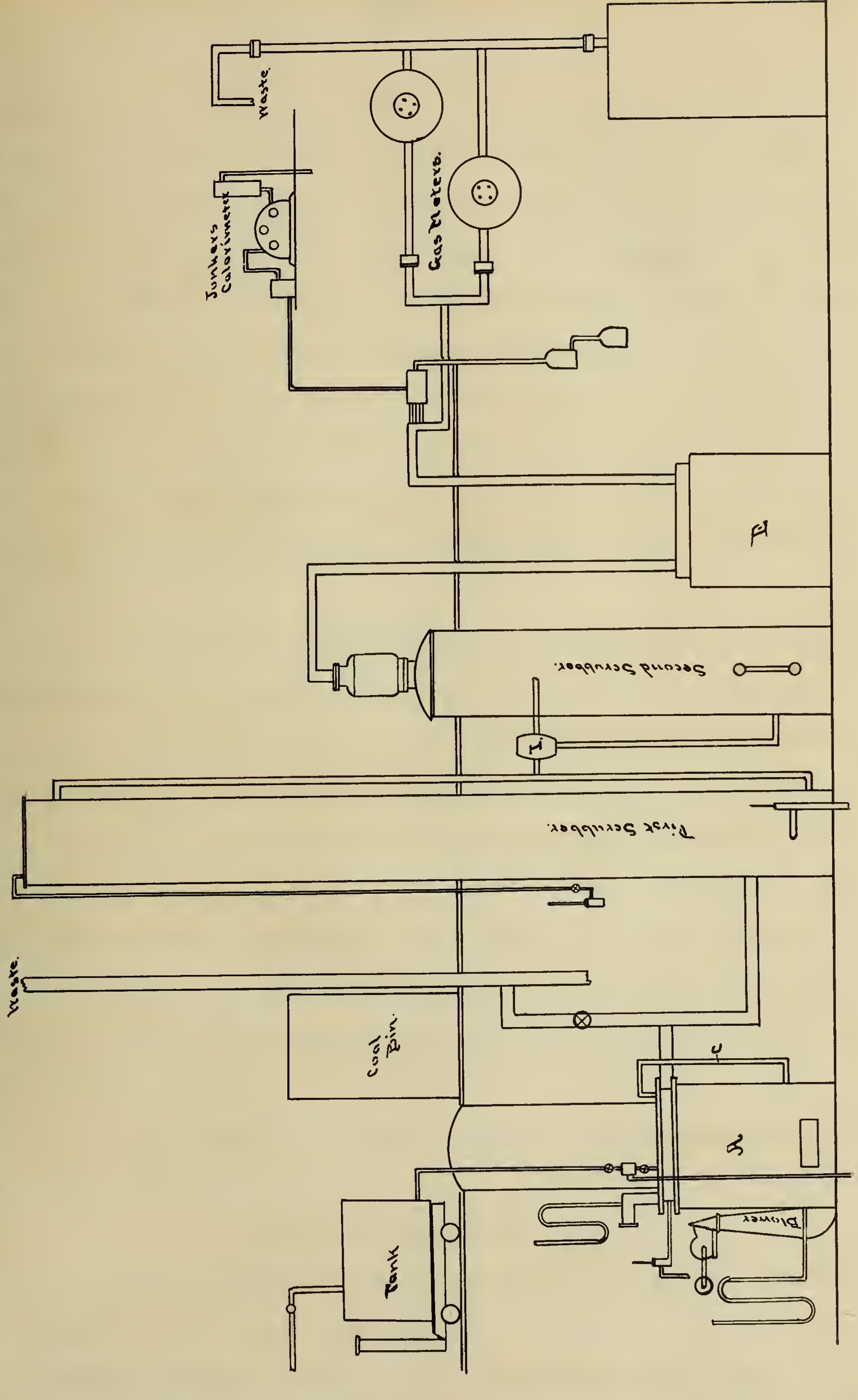
Waste.
Junkers Calorimeter
Gas Meters.
Second Scrubber.
First Scrubber.
Waste.
Coal Bin.
Tank
Blower

Fig 7.

the pressure in the producer is less than atmospheric, thereby preventing the escape of the poisonous gases through the producer. The producer proper is a cylindrical stove (A) lined with fire brick and having a grate at the floor and a charging door at the top. The suction necessary to produce combustion and to draw the gases through the producer is made by the means of the injector (I). The producer has a vaporizer (B), and a portion of the heat of combustion goes to vaporize water. This vapor or steam is carried to the bottom of the fuel bed by means of the pipe (C). This steam is disintegrated and its elements form a part of the resulting producer gas.

From the producer furnace the gases pass to the scrubber. The scrubber is a steel cylinder containing coke over which water trickles. The gases enter at the bottom and leave at the top. This removes the tar and other foreign matter. From the first scrubber the gases pass to the injector where they are mixed with the steam. This mixture then passes to a second scrubber, similar to the first, where the steam is condensed. The gas then passes through the drier (E) where all particles of water and foreign matter,which have passed through the scrubbers, are removed. From the drier the gas goes to the engine.

The gas meter used is made by the Westinghouse Gas Meter Co., Pittsburg, Pa.

Method of Conducting Test.

The apparatus was taken to the engine and placed in readiness for the test. The engine was started by means of compressed air from the compressor in the Laboratory. When the speed

was sufficiently high, the compressed air valve was closed and producer gas was admitted to the cylinder. After the engine had run at full speed for about ten minutes the test was begun. At intervals of ten minutes simultaneous readings (at a signal from a whistle) were taken of the following:

Revolutions per minute.

Explosions per minute.

Gas meter dials.

The four thermometers.

Amount of cooling water.

Cylinder performance (by means of the indicator).

A continuous sample was taken throughout the period of both the fuel and the exhaust gas.

For the fuel sample, the supply pipe was tapped and connected, by means of a rubber tube, to a glass flask filled with about a quart of mercury. When the test was started, gas was allowed to flow through the rubber tube until the air was expelled. Then the tube was connected to the flask and all cocks were open. The lower cock on the flask was adjusted to permit a fine stream of mercury to flow into a glass jar placed beneath the flask. In this manner the flask, originally containing mercury, was filled with gas from the supply pipe.

For the exhaust sample, the exhaust pipe was tapped and connected to a 3 in. x 12 in. drum. A safety valve was interposed between the exhaust pipe and the drum to permit the exhaust gas under high pressure (following an explosion) to enter the drum, and to prevent the admission of air when the engine speed was so

high that no fuel was admitted to the cylinder by the governor. A small vertical pipe, about a yard long and open to the air, was connected to the other end of the drum to prevent excessive pressure and the accumulation of old gas in the drum. From the drum the gas sample was taken as before. When the flasks were nearly filled with gas, they were disconnected, labled, and later analyzed.

Results to be Computed.

The following items are computed:

(1) Area of indicator card - from planimeter.

(2) Mean effective pressure.

(3) Indicated horse-power.

(4) Brake horse-power.

(5) Mechanical efficiency.

(6) Total B. t. u. input.

(7) Total B. t. u. output.

(8) Thermal efficiency.

(9) Vapor pressure.

(10) Dry gas pressure.

(11) Absolute temperatures of gases.

(12) Amount of standard gas.

(13) Total volume of each constituent gas.

(14) Total weight of carbon in fuel gas.

(15) Weight of each gas in sample of 100 cu. ft. of exhaust gas.
Weight of carbon in sample of 100 cu. ft. of exhaust gas.

(16) Total volume of exhaust gas.

(17) Total weight of exhaust gas.

Computations on heat balance:

Debit.

(18) B. t. u. in fuel.

Credit.

(19) B. t. u. in cooling water.

(20) B. t. u. equivalent of indicated horse-power.

(21) B. t. u. absorbed by vapor in fuel gas.

(22) B. t. u. from combustion of hydrogen.

(23) B. t. u. lost from incomplete combustion.

(24) B. t. u. lost by rise in temperature of exhaust gas.

Sample Calculations.

(1) Mean area, by planimeter, --- 0.934 sq. in.

Length of card -------------- 3.2 in.

(2) Mean ordinate = $\frac{.934}{3.2}$ = .292 in.

M. E. P. = .292 x 200 = 58.4 lbs. per sq. in.

(3) I. H. P. = $\frac{PLAN}{33000}$

$= \frac{58.4 \times 1.58 \times 314.16 \times 80.5}{4 \times 33000}$

= 17.7

P = M. E. P.

L = stroke in ft.

A = area of piston in sq. in.

N = explosions per minute.

(4) B. H. P. = $\frac{nDNW}{33000}$

$= \frac{n \times 10.6 \times 222 \times 50}{33000} = 11.2$

(5) Mechanical efficiency = $\frac{B.\ H.\ P.}{I.\ H.\ P.} = \frac{11.2}{17.7}$ = 63.3%

(6) Cu. ft. standard gas = 3,245.

Thermo value = 143.

B. t. u. input = 3,245 x 143 = 464,000.

(7) B. H. P. = 11.2.

B. t. u. output = 11.2 x 2545 x 2.166 = 61,900.

(8) Thermal efficiency $= \frac{61,900}{464,000} = 13.32\%$.

(9) The gas is assumed saturated with water vapor as it comes from the scrubber.

Temperature of fuel gas = 85.5.

From a saturated steam table the pressure of saturated steam at a temperature of 85.5° Fahr. is 0.6 lbs. per sq. in.

(10) Dry gas pressure = total pressure (assumed atmospheric) - vapor pressure.

= 29.7 - 1.21 = 28.49 in. of mercury.

= 14 lbs. per sq. in.

(11) Absolute temperature of entering gas = 85.5 plus 460 = 545.5°.

Absolute temperature of standard gas = 62 plus 460 = 522°.

(12) $\frac{PV}{T} = \frac{P_1 V_1}{T_1}$

P_1 = 30 in. of mercury. P = 28.49

V_1 = ? V = 3558

T_1 = 522° Fahr. (abs.) T = 545.5

Volume standard gas $= \frac{28.49 \times 3558 \times 522}{30 \times 545.5} = 3245$ cu. ft.

(13) Total volume of each constituent gas is equal to the percent (from the analysis) x the total volume of standard gas.

Gas	Anal. by vol.		Total vol.st.gas		Vol. of each constituent gas.
CO_2	6.6	x	3245	=	-------214.0
O_2	0.7	"	"	"	------- 22.7
CO	20.7	"	"	"	-------672.0
CH_4	3.1	"	"	"	-------100.8
H_2	13.9	"	"	"	-------451.0
N_2	55.1	"	"	"	------1790.0

(14) Carbon in each constituent gas = volume of gas times specific weight of gas times percent carbon in gas.

Gas	Volume	Specific weight	Percent of carbon	Wt. carbon.
CO_2	214	.1161	27.3	6.8
CO	672	.074	42.9	21.3
CH_4	100.8	.0428	75.0	3.14
			Total =	31.24lb.C.

(15)

Gas	Analysis		Sp. wt.		Wt. gas		Percent carbon		Wt. carbon.
CO_2	12.35	x	.1161	=	1.433	x	27.3	=	.391
O_2	5.95	"	.0842	"	.501		———		———
CO	.75	"	.074	"	.055	"	42.9	"	.023
CH_4	.1	"	.0428	"	.004	"	75.0	"	.003
H_2	.4	"	.0053	"	.002		———		———
N_2	80.45	"	.074	"	5.96		———		———
			Total --		7.955				.417

(16) Weight carbon in entering gas = weight carbon in exhaust gas.

Wt. carbon in entering gas ---------------- = 31.24 lbs.

Wt. carbon in 100 cu. ft. exhaust gas ----- = .417 lbs.

Volume of exhaust gas = $\frac{31.24}{.417}$ x 100 = 7500 cu. ft.

(17) Weight of 100 cu. ft. exhaust gas = 7.955 lbs.

No. of hundreds of cu. ft. = 75.

Total weight of exhaust gas = 7.955 x 75 = 596 lbs.

(18) B. t. u. per cu. ft. = 143.

No. of cu. ft. of fuel (standard gas) = 3245.

Total B. t. u. in fuel - from No. (6) - = 464,000.

(19) Total No. of lbs. of cooling water = 2245.

Rise in temperature of cooling water = 49°.

B. t. u. absorbed by cooling water = 49 x 2245 = 110,000.

(20) Duration of test --- 2 hrs., 10 min.

One H. P. hour = 2545 B. t. u.

I. H. P. = 17.7.

B. t. u. equivalent of work = 2545 x 17.7 x 2.166 = 97,500.

(21) The gas entering the cylinder is assumed to be saturated with water vapor. From a saturated steam table the specific volume of steam at 85.5° is 545.

No. of cu. ft. of gas under operating conditions = 3558.

Total No. of lbs. of water in fuel = $\frac{3558}{545}$ = 6.53.

Specific heat of superheated steam = 0.5.

Rise in temperature, 85 - 700°.

B. t. u. absorbed by water vapor in fuel = 6.53 x .5 x (700-85)
= 2000.

(22) Total volume of hydrogen = 451 cu. ft. (standard gas).

Specific weight of hydrogen = 0.0053.

Weight of free hydrogen in fuel = 451 x .0053 = 2.4 lbs.

Total volume of methane gas = 100.8.

Specific weight of methane gas = .0428.

Percent of hydrogen in methane gas = 25.

Weight of hydrogen in methane gas = 100.8 x .0428 x .25
= 1.08 lbs.

Total weight of combined hydrogen in fuel = 3.48 lbs.

Percent of hydrogen in exhaust gas = 0.4.

Volume of exhaust gas = 7500 cu. ft.

Volume of hydrogen in exhaust gas = .004 x 7500 = 30 cu. ft.

Weight of hydrogen in exhaust gas = 30 x .0053 = .159 lbs.

Weight of hydrogen = 3.48 - .159 = 3.32 lbs.

Weight of water = 9 x 3.32 = 29.88 lbs.

B. t. u. = 29.88 x (1146 x 0.5 x) 700 - 212 (- 30)= 40,600.

(23) Volume of exhaust gas = 7500 cu. ft.

Sp. Wt. of exhaust gas = .0795.

Sp. heat = 0.3.

Change in temperature = 700 - 62 = 638°.

B. t. u. = 7500 x .0795 x 0.3 x 638 = 114,500.

(24) B. t. u. for cu. ft. of exhaust gas = 4.5.

Volume of exhaust gas = 7500 cu. ft.

B. t. u. = 4.5 x 7500 = 33,700.

Heat Balance.

Debit.

B. t. u. in fuel	464,000.

Credit.

B. t. u. in cooling water.	110,000.
B. t. u. equivalent of indicated horse-power.	97,500.
B. t. u. absorbed by vapor in fuel gas.	2,000.
B. t. u. by combustion of hydrogen.	40,600.
B. t. u. lost from incomplete combustion.	33,700.
Sensible heat in exhaust gas.	114,500.

Conclusions.

By reference to the above data it will be seen that the mechanical efficiency is rather low. This is probably due to the

improper design of the reciprocating parts, which resulted in excessive friction. The largest heat loss occurs in the cooling water, and in the exhaust gas. The thermal efficiency is about 13.32%.

10 H. P. Test.

Producer Gas.

r. p. m.	Ex. per min.	Gas Meter		Weight of Cooling Water			Temperatures					Area of Card
							Gas		Cooling Water			
		Init.	Net	In.	Fin.	Net	Ent.	Ex.	Ent.	Leav.	Diff.	
223	78	86978	000	178	330	152	93.0	635	58.0	107.0	49.0	0.98
222	79	87219	241	330	505	175	93.0	678	58.0	107.0	49.0	0.98
222	77	87591	362	505	695	190	93.0	694	58.5	107.5	49.0	0.94
222	77	87757	166	695	890	195	93.0	695	58.5	107.5	49.0	0.97
223	78	88009	252	180	370	190	93.0	694	58.0	107.5	49.5	1.03
222	81	88284	275	370	550	180	82.0	704	58.5	108.2	49.7	0.92
223	78	88542	258	550	725	175	82.0	708	58.5	108.0	49.5	1.00
222	99	88798	256	725	870	145	82.0	716	58.5	107.3	48.8	0.92
222	72	89055	267	180	330	150	82.0	709	58.5	106.0	47.5	0.85
222	74	89435	380	330	515	185	82.0	698	58.5	104.8	46.3	0.83
222	85	89688	253	515	690	175	82.5	698	58.0	107.2	49.2	0.97
220	87	89956	268	690	850	160	82.5	698	58.0	106.8	48.8	0.86
222	80	90255	299	850	1023	173	82.5	712	58.0	106.0	48.0	0.80
222	80	90536	281				82.5	719	58.0	106.5	48.8	0.93
		Total-	3558		Total-	2245						
Mean												
222	80						82.5	709	58.0	107.3	48.6	0.93

$$\text{M.E.P.} = \frac{0.93 \times 200}{3.2} = 58.4$$

$$\text{I.H.P.} = \frac{\text{PLAN}}{33000} = \frac{58.4 \times 1.58 \times 314.16 \times 80}{4 \times 33000} = 17.7$$

$$\text{B.H.P.} = \frac{2\text{nRNW}}{33000} = \frac{2 \times 3.14 \times 5.3 \times 50 \times 222}{33000} = 11.2$$

W = 50 lbs.   R (length of brake arm) = 5.3 ft.

Efficiency Test of Otto Gas Engine on Illuminating Gas.

Object.

The object of this test was to obtain data for determin- the mechanical and thermal efficiencies, and the heat balance of the engine running on illuminating gas, under a constant load of 10 H.P.

Apparatus.

The following apparatus was uses: The Otto gas engine No. 8965, 220 R. P. M., 23 H. P., cylinder 10 x 19 in., 4 cycle.

One thermometer ----- range 0 - 1000° Fahr.

One thermometer ----- range 0 - 200° Fahr.

Two thermometers ---- range 0 - 100° Fahr.

Crosby indicator No. 6183, spring No. 50, scale 400, 1/8 in. piston.

Gas meter No. 122300, range 0 - 100,000,000 cu. ft.

Prony brake.

Two Buffalo Scales.

Speed counter.

Water tank ----- No. 287.

Description of Apparatus.

With the exception of the gas producer, the same apparatus was used as in the test with producer gas, and is described on page 14.

Method of Conducting Test.

The test was conducted in exactly the same manner as the test on producer gas. For a description of the method see page 14.

Rusults to be Computed.

The same items were computed as in the test on producer gas. These items are listed on page 16.

Sample Calculations.

The calculations were similar to those made on the data from the test on producer gas. See page 17.

10 H.P. Test.

Illuminating Gas.

r. p. m.	Ex. per min.	Gas Meter		Weight of Cooling Water			Temperatures					Area of Card
							Gas		Cooling Water			
		Init.	Net	In.	Fin.	Net	Ent.	Ex.	Ent	Leav.	Diff.	
219	57	95822	000	690	902	212	72.5	538	58.0	105.0	47.0	0.96
221	56	95880	68	902	1105	203	72.5	558	58.0	108.0	50.0	1.00
220	55	95953	72	1105	1300	195	72.5	582	57.0	110.0	62.0	1.08
220	54	96025	72	1300	1500	200	72.5	590	57.0	122.0	65.0	1.02
221	51	96091	67	1500	1700	200	72.5	582	57.0	120.0	63.0	0.96
221	49	96162	71	1700	1900	200	73.0	590	57.0	119.0	62.0	1.02
220	52	96235	73	1900	2107	207	73.0	610	58.0	122.0	64.0	1.05
221	50	96301	65	2107	2307	200	73.0	604	58.0	124.0	66.0	0.96
222	49	96380	81				73.0	608	58.0	128.0	70.0	1.04
		Total	-558		Total-	1617						
Mean												
220	52						72.7	585	57.5	118.5	61.0	1.01

$$\text{M.E.P.} = \frac{1.01 \times 400}{3.3} = 122.3$$

$$\text{I.H.P.} = \frac{PLAN}{33000} = \frac{122.3 \times 19 \times 314.16 \times 52.4}{12 \times 4 \times 33000} = 24.2$$

$$\text{B.H.P.} = \frac{2\pi RNW}{33000} = \frac{2 \times 3.14 \times 5.3 \times 50 \times 220}{33000} = 11.2$$

W = 50 lbs. R = (length of brake arm) = 5.3 ft.

Efficiency Test of Otto Gas Engine

on Illuminating Gas.

15 and 20 H. P.

These tests are similar to the 10 H. P. test with illuminating gas described on page 24.

15 H.P. Test.

Illuminating Gas.

r.p.m.	Ex. per min.	Gas Meter		Weight of Cooling Water			Temperatures					Area of Card
							Gas		Cooling Water			
		Init.	Net	In.	Fin.	Net	Ent.	Ex.	Ent.	Leav.	Diff	
220	77	97574	000	131	395	264	71.0	636	58.0	108.0	50.0	0.86
222	76	97650	76	395	650	255	71.0	668	58.0	108.0	50.0	1.04
220	76	97722	72	130	395	265	71.0	684	58.0	102.0	44.0	1.00
220	74	97793	71	395	660	265	71.0	686	58.0	110.0	52.0	1.00
220	75	97866	73	660	921	261	71.0	694	58.0	107.0	49.0	1.00
219	74	97943	77	123	420	295	71.0	694	58.0	106.0	48.0	1.02
218	73	98020	77				71.0	696	58.0	105.0	47.0	1.08
		Total	- 446		Total-	1605						
Mean												
219	75						71.0	679	58.0	106.0	48.6	1.00

$$M.E.P. = \frac{1.00 \times 400}{3.3} = 121.0$$

$$I.H.P. = \frac{PLAN}{33000} = \frac{121.0 \times 19 \times 314.16 \times 75}{12 \times 4 \times 33000} = 34.3$$

$$B.H.P. = \frac{2nRNW}{33000} = \frac{2 \times 3.14 \times 5.3 \times 75 \times 219}{33000} = 16.5$$

W = 75 lbs. R (length of brake arm) = 5.3 ft.

20 H.P. Test.

Illuminating Gas.

r. p. m.	Ex. per min.	Gas Meter Init.	Gas Meter Net	Weight of Cooling Water In.	Weight of Cooling Water Fin.	Weight of Cooling Water Net	Temperatures Gas Ent.	Temperatures Gas Ex.	Temperatures Cooling Water Ent.	Temperatures Cooling Water Leav.	Temperatures Cooling Water Diff.	Area of Card
218	90	96617	000	770	1185	415	72.5	754	58.0	104.0	46.0	0.97
218	91	96738	121	1185	1600	415	72.5	810	58.0	104.0	46.0	1.04
209	106	96861	123	1600	2015	415	72.5	886	58.0	108.0	50.0	1.03
216	108	96991	130	2015	2415	400	72.5	918	58.0	110.0	52.0	0.94
220	110	97215	124	2415	2830	415	72.5	932	58.0	110.0	52.0	0.97
208	104	97253	128	2830	3245	415	72.5	940	58.0	111.0	53.0	0.97
204	102	97381	128				72.5	940	58.0	106.0	48.0	0.94
		Total	-764		Total	-2475						
Mean												
213	101						72.5	883	58.0	107.6	49.6	0.97

$$M.E.P. = \frac{0.97 \times 400}{3.3} = 117.5$$

$$I.H.P. = \frac{PLAN}{33000} = \frac{117.5 \times 19 \times 314.16 \times 101.5}{12 \times 4 \times 33000} = 44.9$$

$$B.H.P. = \frac{2nRNW}{33000} = \frac{2 \times 3.14 \times 5.3 \times 100 \times 213.3}{33000} = 22.4$$

W = 100 lbs. R (length of brake arm) = 5.3 ft.

Gas Analyses.

10 H.P. Test.

Illuminating Gas.

	Exhaust Gas.	Intake Gas.
$C\ O_2$	2.7	6.8
O_2	15.7	2.5
$C\ O$	0.0	14.6
C_2H_4	0.0	9.5
$C\ H_4$	0.7	38.5
H_2	1.0	3.1
N_2	79.9	25.1
B.T.U.	10.0	582.0

Gas Analyses.

15 H.P. Test.

Illuminating Gas.

	Exhaust Gas	Intake Gas.
$C\ O_2$		3.8
O_2		2.7
$C\ O$		20.1
C_2H_4		1.8
$C\ H_4$		23.6
H_2		32.1
N_2		15.9
B.T.U.		435.0

Gas Aħalyses.

20 H.P. Test.

Illuminating Gas.

	Exhaust Gas.	Intake Gas.
CO_2	9.2	5.1
O_2	1.6	0.6
CO	5.0	26.6
C_2H_4	0.7	1.1
CH_4	1.6	22.7
H_2	3.2	30.8
N_2	78.7	13.1
B.T.U.	53.0	431.0

Gas Analyses.

10 H.P. Test.

Producer Gas.

	Exhaust Gas.	Intake Gas.
CO_2	12.3	6.6
O_2	5.9	0.7
CO	0.7	20.7
C_2H_4	0.1	3.1
H_2	0.4	13.9
N_2	80.4	55.1
CH_4	0.0	0.0
B.T.U.	4.5	143.0

Heat Distribution.

Test	Heat Units		
	Transferred into Work. %	Taken by the jacket Water %	Latent Heat in Exhaust %
I	13.3	23.7	7.25
II	11.5	31.0	3.90
III	22.4	41.0	
IV	18.0	38.7	28.50